2021 DOE OE ENERGY STORAGE PROGRAM REVIEW

TEXAS
The University of Texas at Austin

SPEC
Semiconductor Power Electronics Center

GAN ENABLED EFFICIENT PLUG-AND-PLAY BATTERY ENERGY STORAGE SYSTEM

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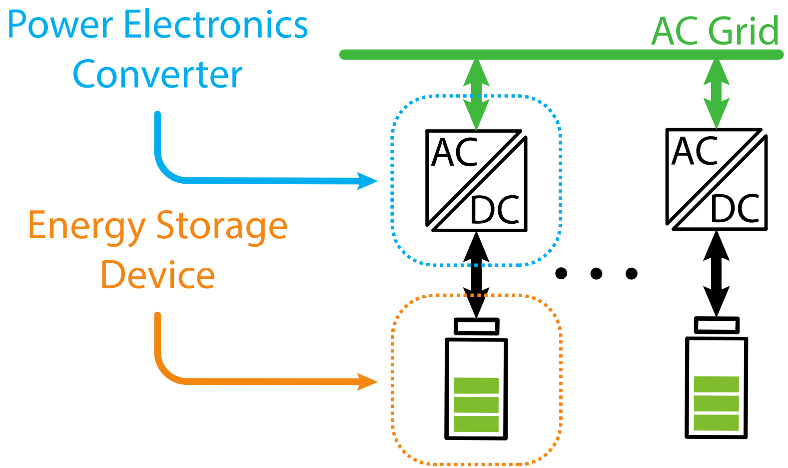
Better and Lower Cost Battery Energy Storage System



High voltage battery pack (100-400V)
high BMS/BOS cost

or

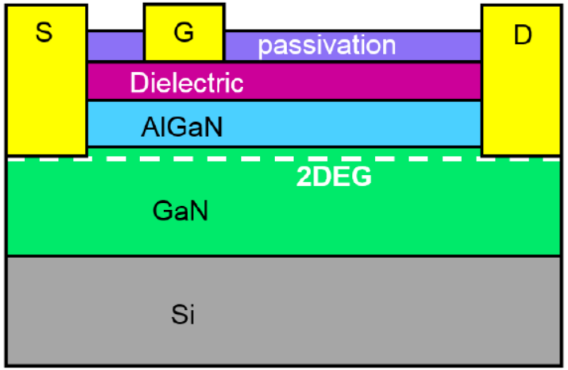
Low voltage battery pack (12 to 48V)
Lower BMS/BOS cost
Better SOC utilization
More difficult in power electronics
high current on battery side
isolated topology needed

Battery Cell are all low voltage
- Li-ion: 3.0-3.6V
- Flow battery: 1.0 to 2.43V
- Zn-MnO2: 0.9-1.7V

Battery pack

[1] M. T. Lawder *et al*., "Battery Energy Storage System (BESS) and Battery Management System (BMS) for Grid-Scale Applications," in *Proceedings of the IEEE*, vol. 102, no. 6, pp. 1014-1030, June 2014.

But there is a new PE solution: GaN



600V Devices Compared

600V FETs	Ron (mohm)	Ciss (nF)	FOM 1 (Ron*Ciss)	Coss (nF)@400V	FOM2 (Ron*Coss)	Qrr(uC)	FOM3 (Ron*Qrr)
Si SJ	37	7.24	267	0.38	14	36	1332
SiC MOS	120	1.2	144	0.09	10.8	0.053	6.3
GaN HFET	25	.52	13	0.13	3.25	0.113	2.8

Si SJ: Infineon IPW65R037C6. SiC MOSFET: Rohm SCT2120AF GaN HFET: GaNSystem GS66516T

- Gate loop is getting faster & faster
- Switching loss reduction

Turn-on loss ~ FOM2

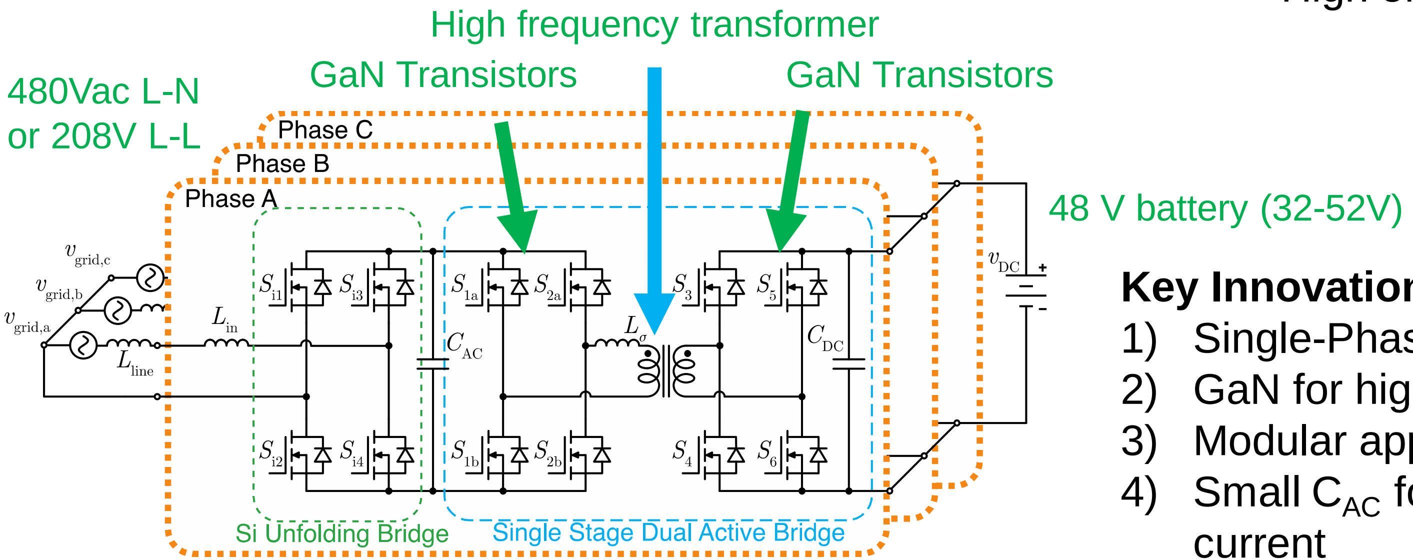
Reverse recovery charge/loss Basically eliminated in WBG devices Good for inverter applications

Project Objective

Specifications	
Rated grid voltage	480V / 208V Three Phase
Rated power	10kW
Rated battery voltage range	48 V / 32 - 52 V
Battery types	Flow battery/ZnMnO2/Li-ion

Power Electronics Challenges

- DC/AC conversion
- High step up voltage ratio
- Bidirectional power flow
- High DC current
- High efficiency

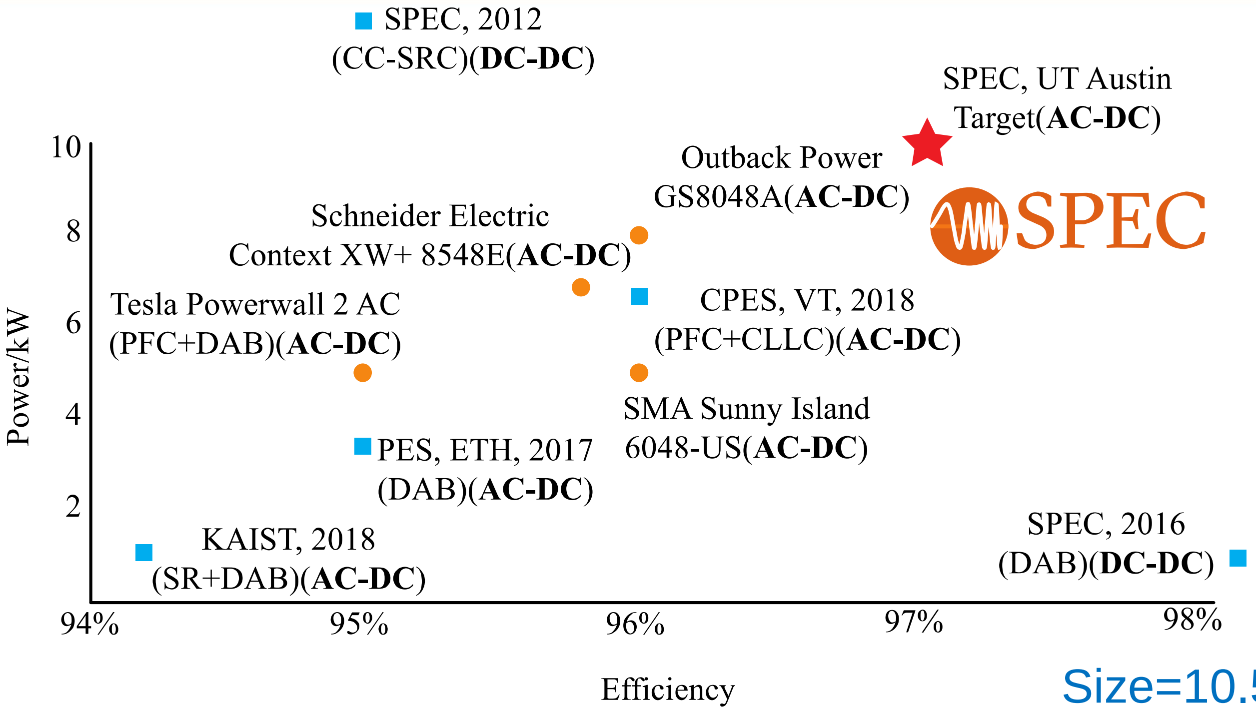


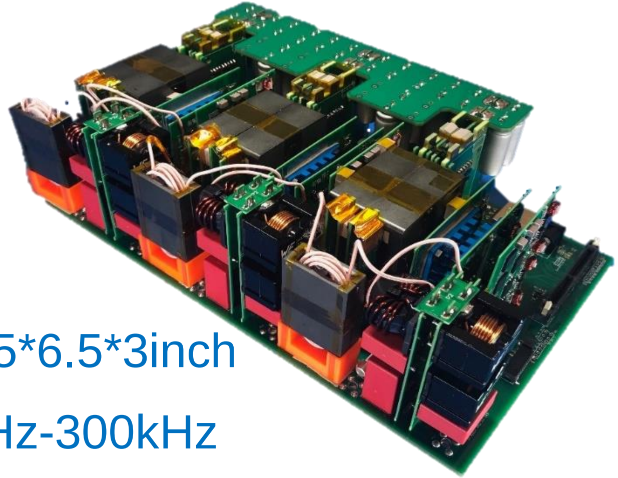
3-Phase Single-Stage AC/DC Bidirectional Converter

Key Innovations

1) Single-Phase Single-Stage DC/AC
2) GaN for high efficiency and density
3) Modular approach to support scaling
4) Small C_{AC} for low AC side inrush current
   - Enable Plug-and-play
   - Wireless/remote control

Accomplishments: PE Advancement





Size=10.5*6.5*3inch

fsw=50kHz-300kHz

Peak efficiency=97%

[1] http://files.sma.de/dl/15216/SIGEN-11FD1212.pdf
[2] http://www.outbackpower.com/downloads/documents/inverter_chargers/radian_8048a_4048a/radianseries_8048a_4048a_specsheet.pdf
[3] https://41j5tc3akbrn3uezx5av0jj1bgm-wpengine.netdna-ssl.com/wp-content/uploads/2017/09/DS20170928_Conext-XW-230V-Datasheet.pdf
[4] B. Li, Q. Li and F. C. Lee, "A WBG based three phase 12.5 kW 500 kHz CLLC resonant converter with integrated PCB winding transformer," 2018 IEEE Applied Power Electronics Conference and Exposition (APEC), San Antonio, TX, 2018, pp. 469-475.
[5] J. Everts, "Closed-Form Solution for Efficient ZVS Modulation of DAB Converters," in IEEE Transactions on Power Electronics, vol. 32, no. 10, pp. 7561-7576, Oct. 2017.
[6] O. Kwon, J. Kim, J. Kwon and B. Kwon, "Bidirectional Grid-Connected Single-Power-Conversion Converter With Low-Input Battery Voltage," in IEEE Transactions on Industrial Electronics, vol. 65, no. 4, pp. 3136-3144, April 2018.

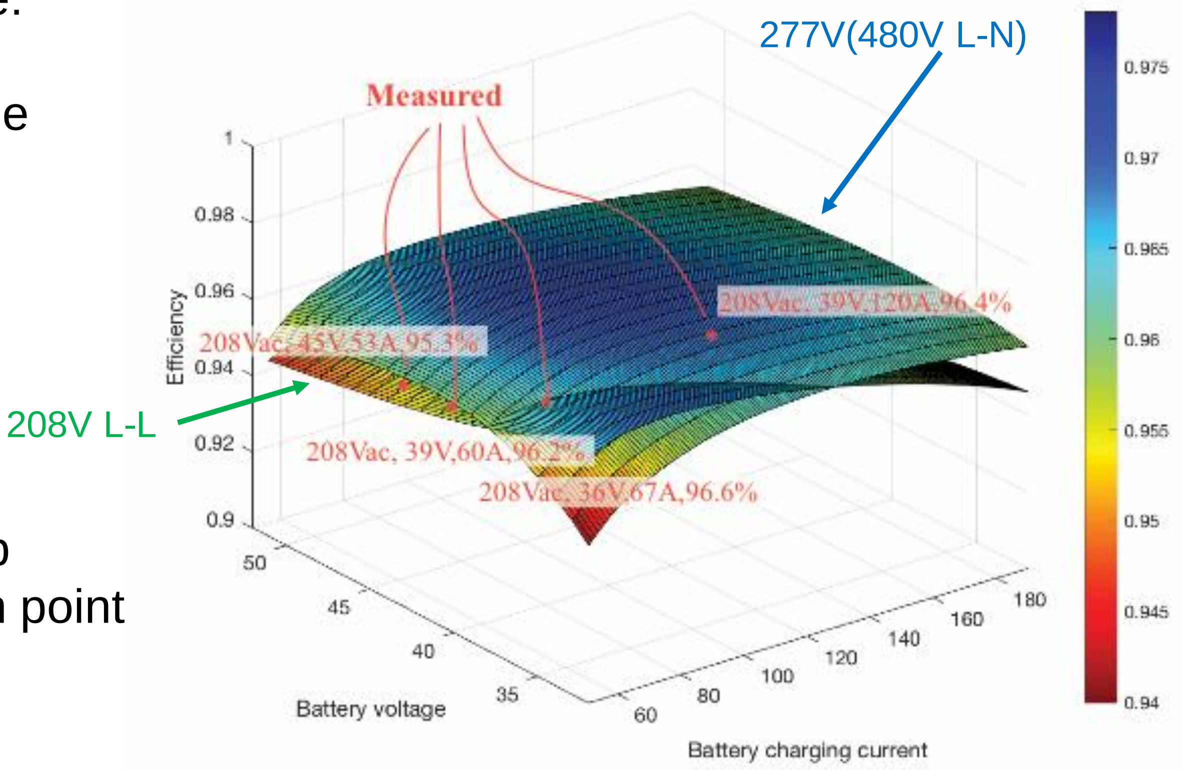
Accomplishments: Efficiency Optimization

Power Electronics Challenge:

- Universal input
- Wide battery voltage range
- Wide range of current

Efficiency optimization

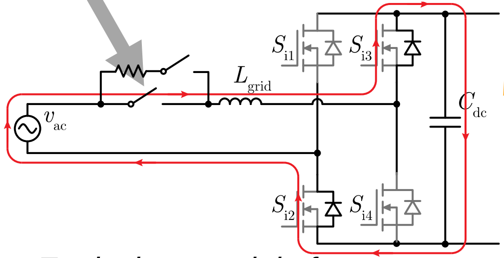
- Overall flat efficiency map
- Optimal efficiency in each point



Accomplishments: Relay-less, plug and play

*Typical 3 phase contactor, 20A, 53.5*63.1*95.8mm**

Typical 500u-10mF



Equivalent model of two-stage AC capacitor charging

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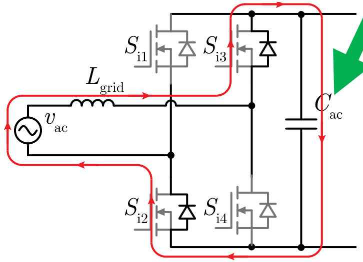
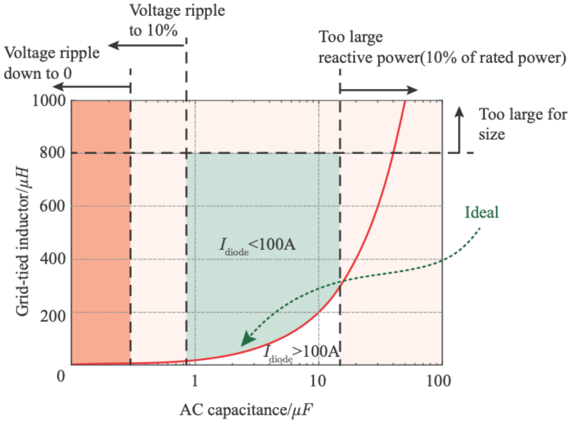
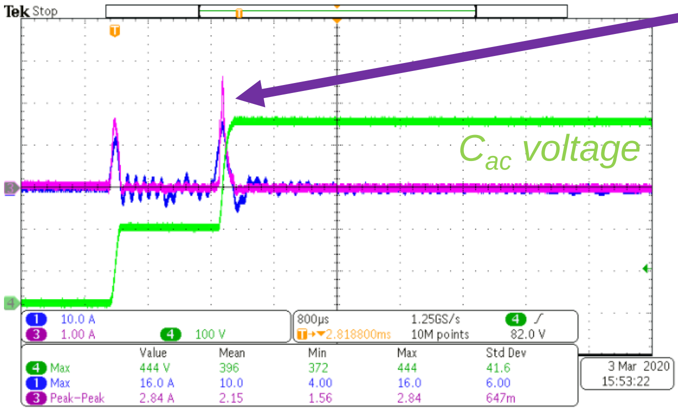


Equivalent model of single-stage AC capacitor charging

Ideal AC cap and grid interface inductor selection



Diode peak current:15.3A
(Current scale of 5)



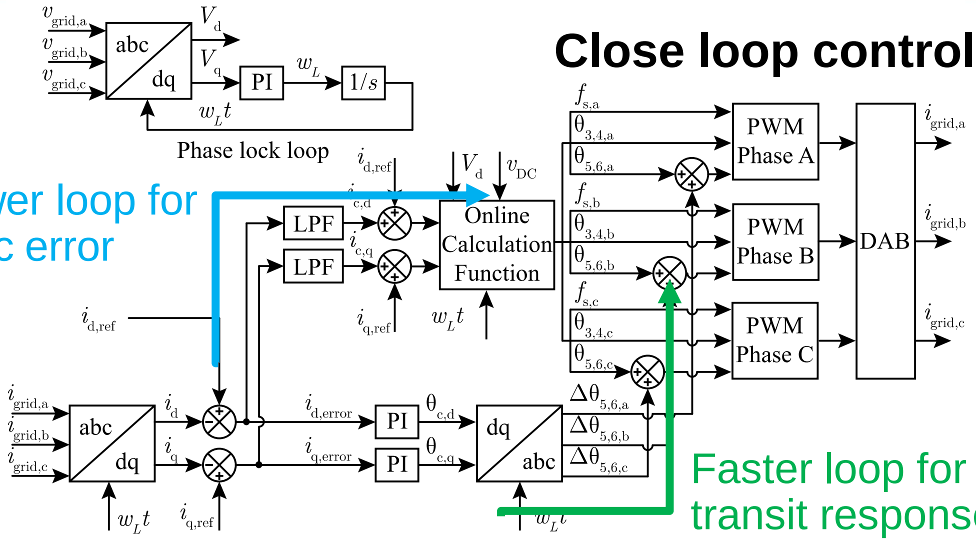
*Inrush current test waveform with 208V grid***

*22.44.0.024.4310, Finder Relays, Inc.

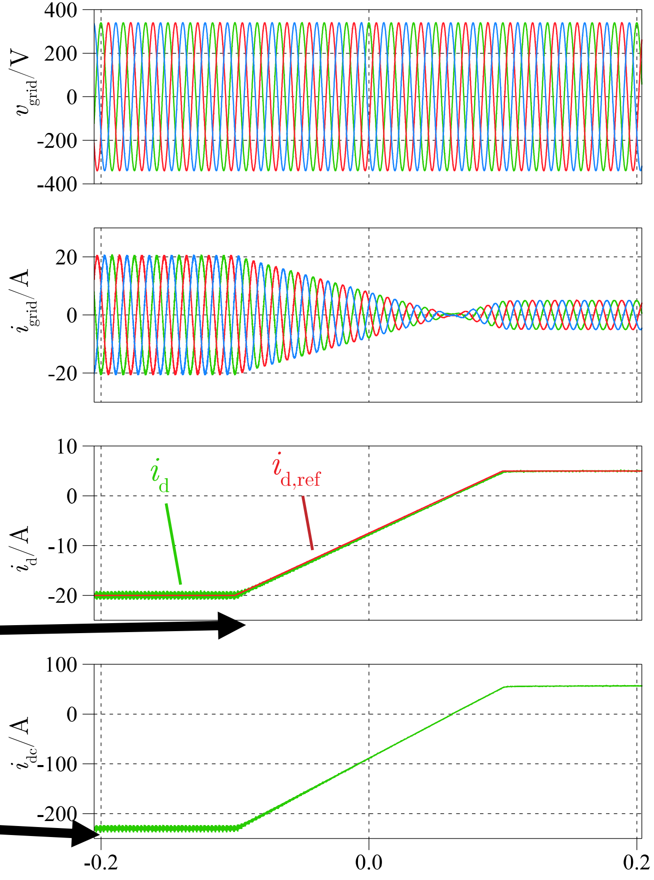
* *Test for more than 20 and chosen from highest value

Accomplishments: Controller

Close loop control



Proposed close loop diagram for three phase single stage DAB.

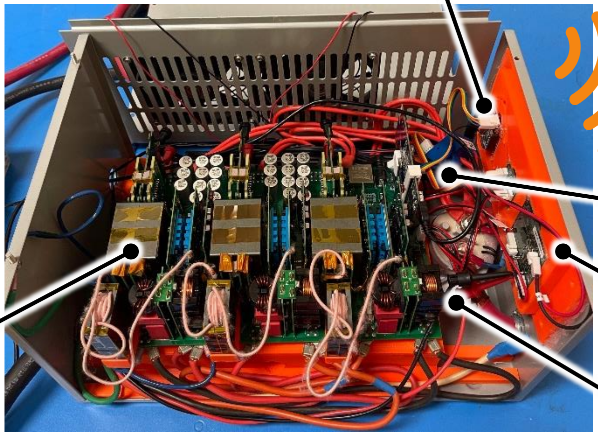


Charging Speed Change Command from -20A(discharging) to 5A(charging)

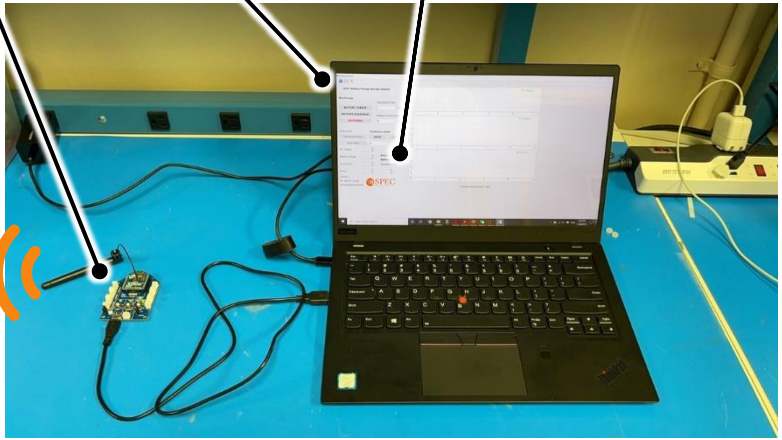
6% High Frequency Ripple (12A ripple at 200A discharging, 3A ripple for 50A discharging)

Transient simulation 200A discharging to 50A charging Vac=480V

Enclosure with Plug-and-Play, Wireless Control



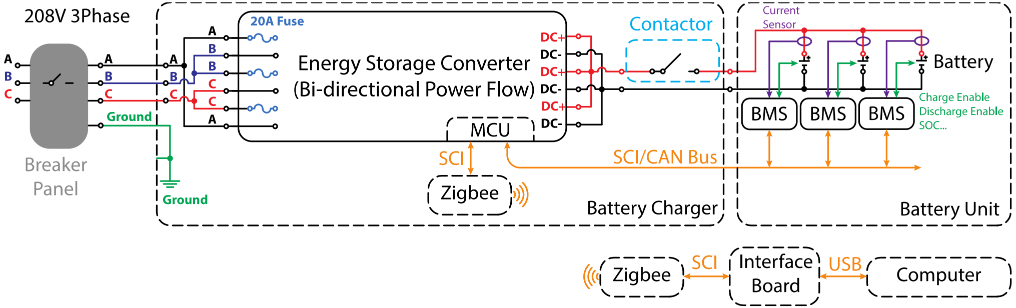
Prototype inside modular enclosure



Computer with wireless receiver with HMI

Battery Charger Unit Mechanical Model

- *Enclosure:* $10"(w) \times 15"(d) \times 8"(h)$;
- *Converter:* $6.5"(w) \times 10.5"(d) \times 3"(h)$;



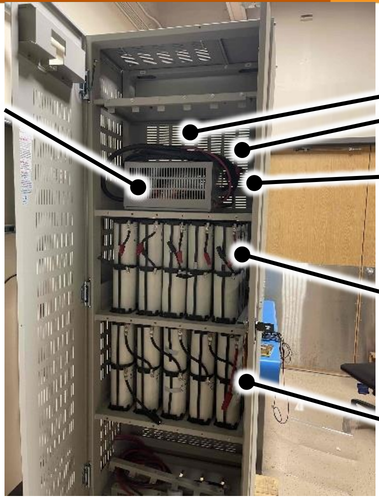
System wiring diagram with connection to 208V grid

Accomplishments: Tested with different batteries

Li-ion battery
AC cable outlet
Charger
Battery cable outlet

Li-ion battery

Charger



AC Cable outlet
Battery Cable outlet
Bus bar
Battery pack 1 (UEP battery)
Battery pack 2 (UEP battery)

UEP battery (ZnMnO2)

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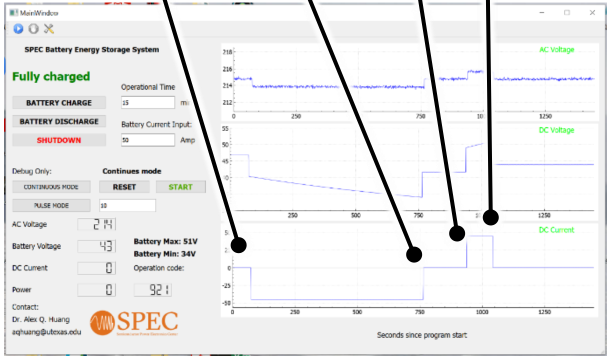
Start charging
Stop charging
Start discharging
Stop discharging

Captured data for Li-ion battery charging/discharging

Data also recorded in .tsv

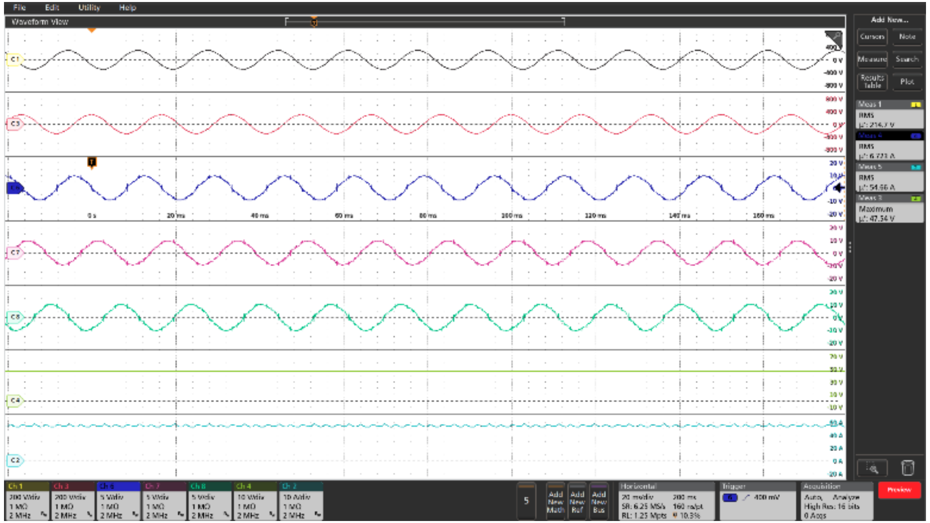
Stop charging
Start charging
Start discharging
Stop discharging



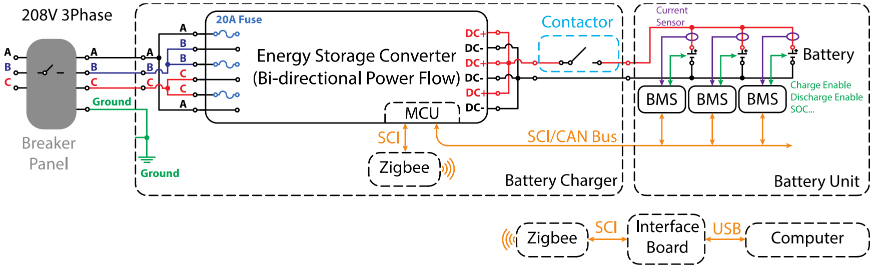
Captured data for UEP battery charging/discharging

Accomplishments: Battery Integration and Test

vab
vbc
ia
ib
ic
vdc
idc

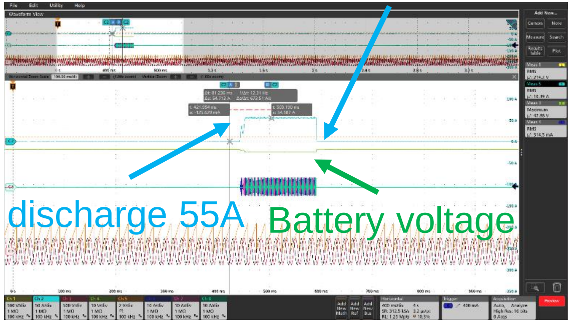


Grid voltage vab, vbc, grid current ia ib ic, DC battery vdc and battery current idc for ***battery discharging*** *at 55A, 47.5V with 208V grid*



System wiring diagram with connection to 208V grid

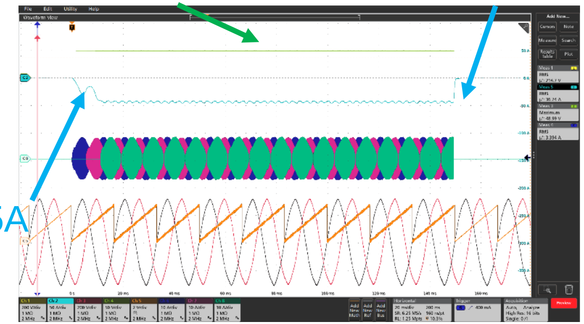
Stop discharge



Start discharge 55A
Battery voltage

Transient waveform for jump start to 55A discharging and stop after 200ms

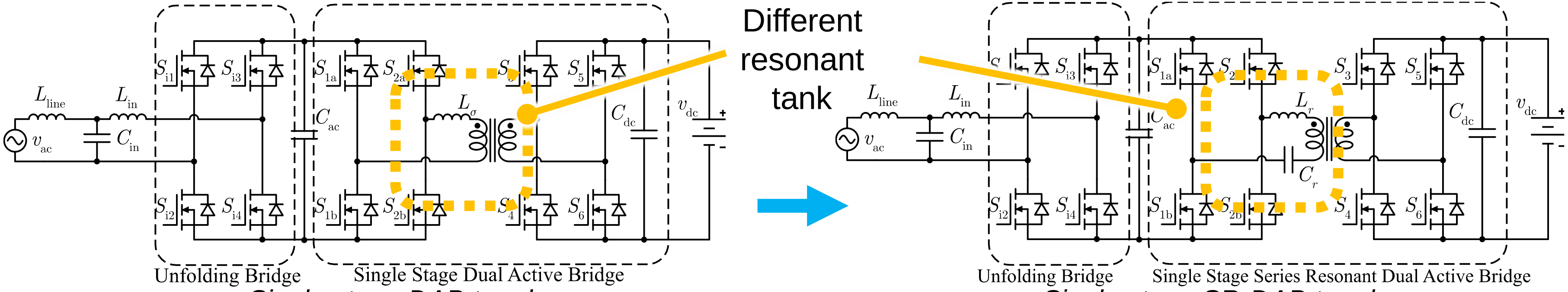
Battery voltage
Stop charge



Start charge 45A

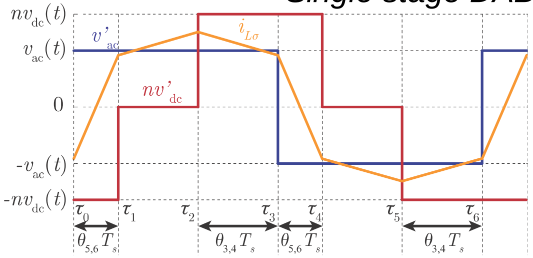
Transient waveform for jump start to 45A charging and stop after 200ms

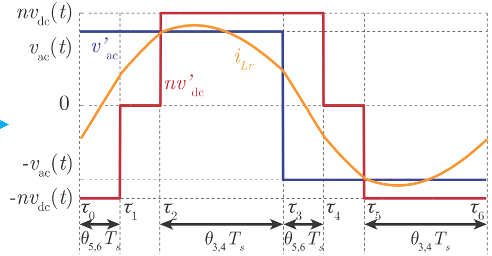
Accomplishments: Circuit innovation



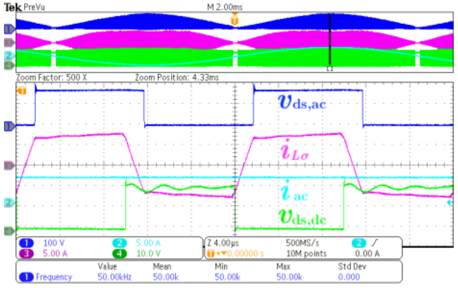
Single stage DAB topology

Single stage SR-DAB topology

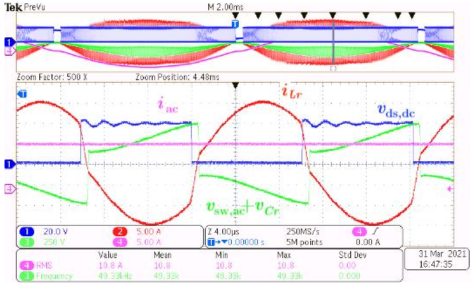




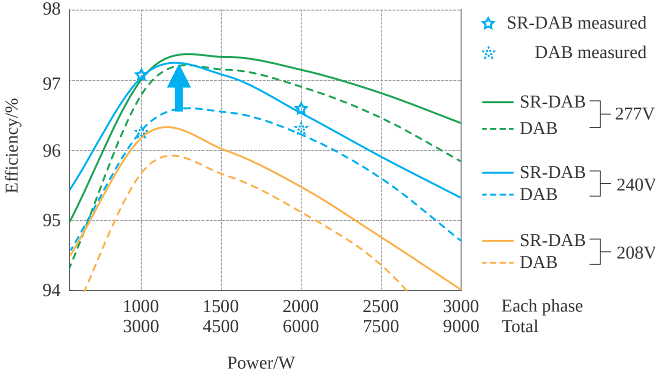
Project improvement of 0.5% efficiency increase



Detailed Operating Waveform for DAB



Detailed Operating Waveform for srDAB



Calculated and measured efficiency for DAB and srDAB w/ 48V voltage battery

Future Plan

- Parallel operation of multiple storage unit
- Parallel operation of multiple chemistry units
- Next generation design: Integrate battery into the power electronics: Battery and PE direct integration into a single plug-and-play unit, reduce size by another 50% vs. today's solution

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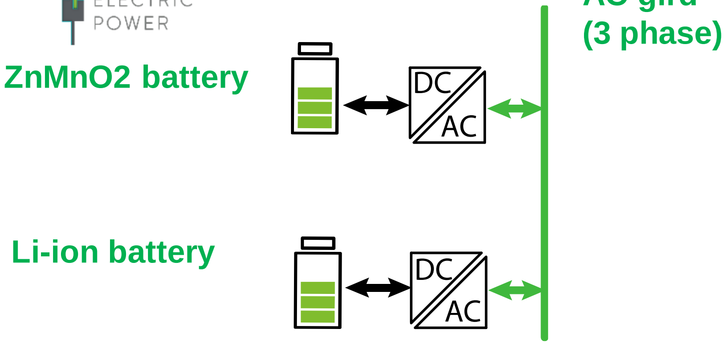
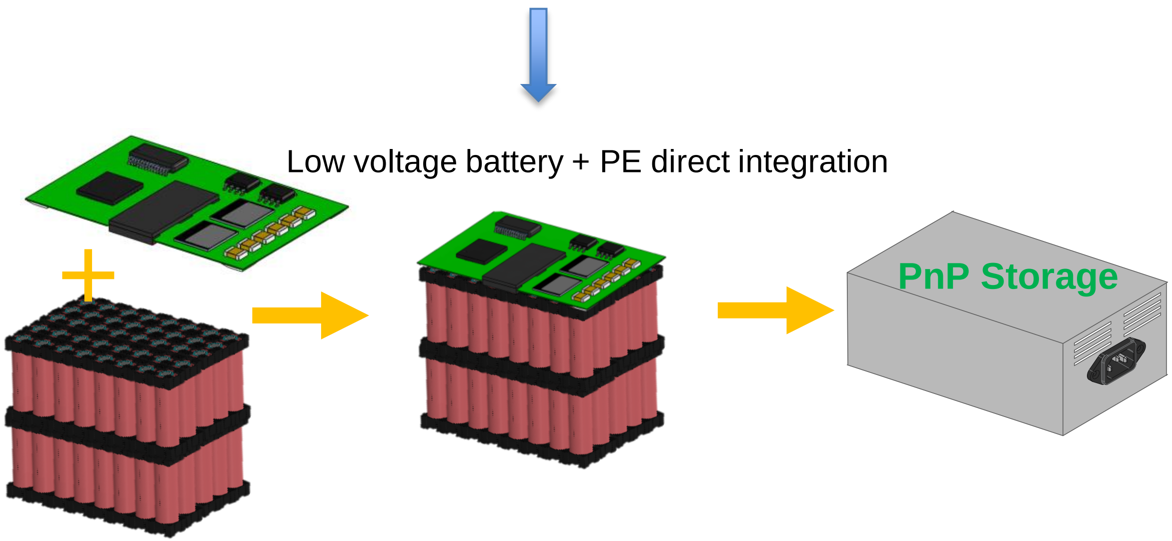


Parallel operation of existing GaN charger

Low voltage battery + PE direct integration



	kWH/L	kW/L	kW/kg
Current Design	0.22	0.15	0.1
New Design	0.39	0.39	0.2
Improvement	77%	160%	100%

THANK YOU!

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U.S. DEPARTMENT OF ENERGY

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Sandia National Laboratories

For more info about this project: please contact Dr. Alex Huang, aqhuang@utexas.edu